James Webb Space Telescope and Standard Model of Cosmology

Chitta Ranjan Das

Bogoliubov Laboratory of Theoretical Physics (BLTP), The Joint Institute for Nuclear Research (JINR)

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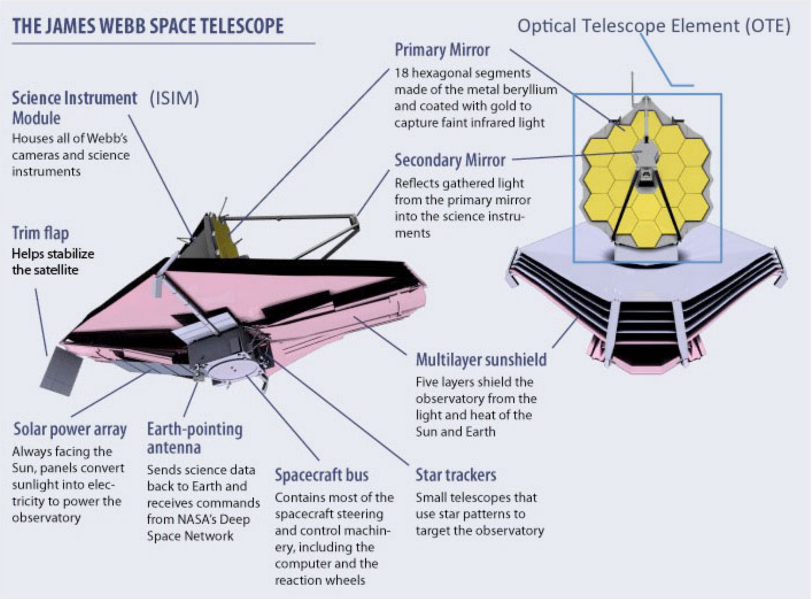
arXiv: 2210.14915

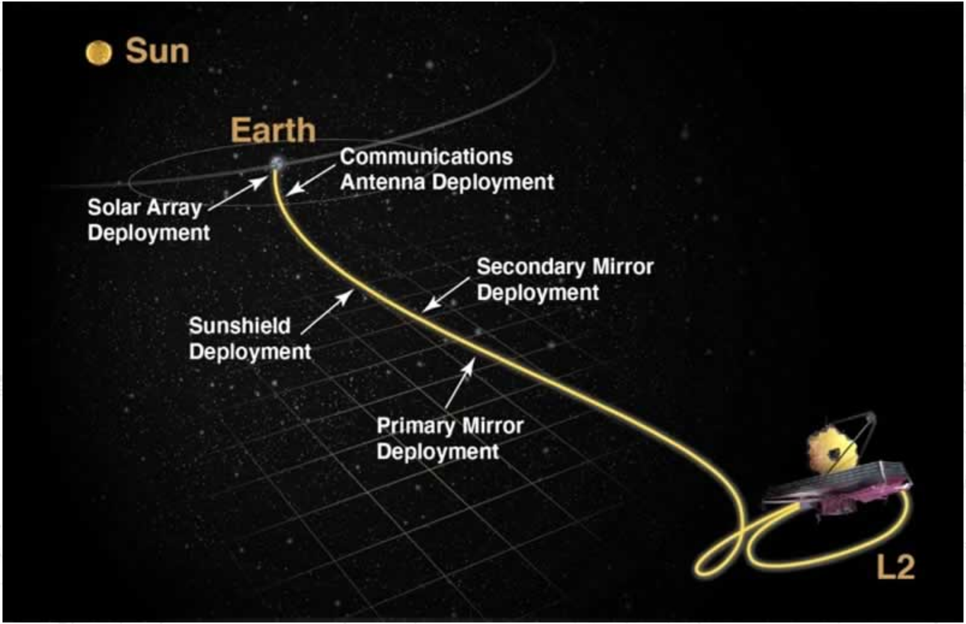
Astrophysics

Preliminaries

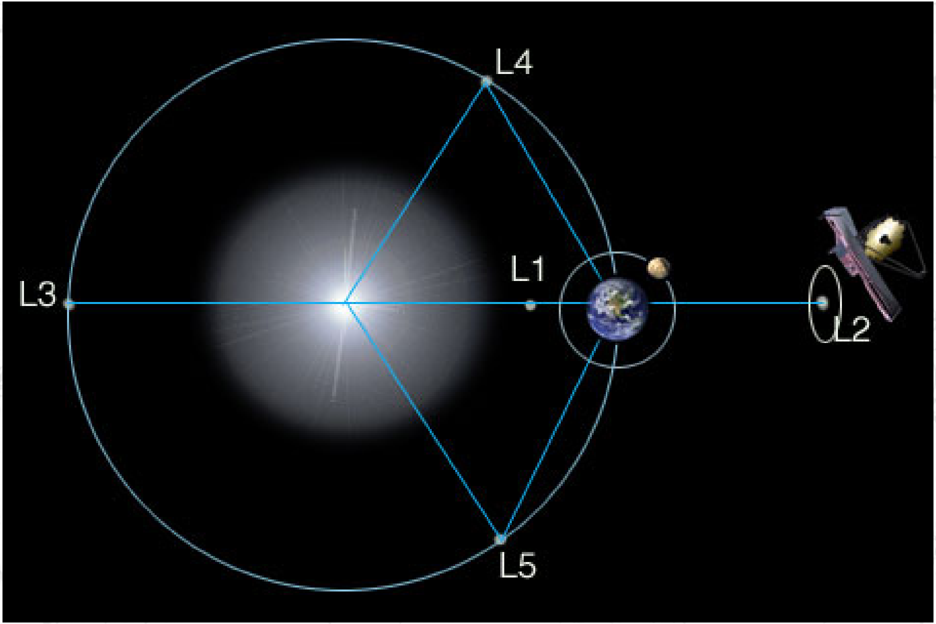
James Webb Space Telescope (JWST), Lambda Cold Dark Matter (ΛCDM)



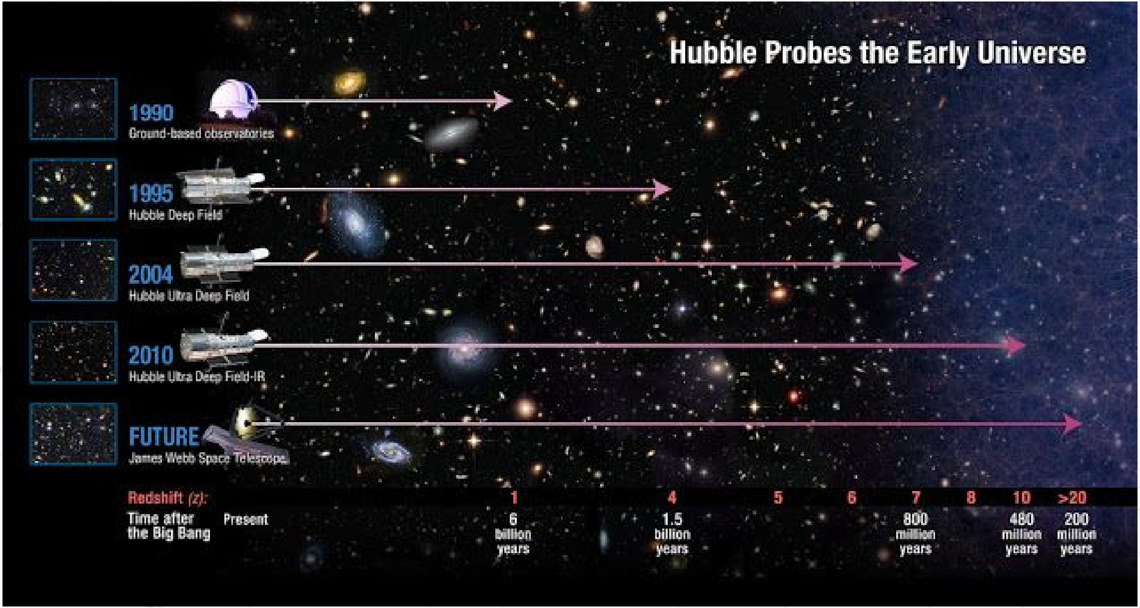
James Webb Space Telescope (JWST)



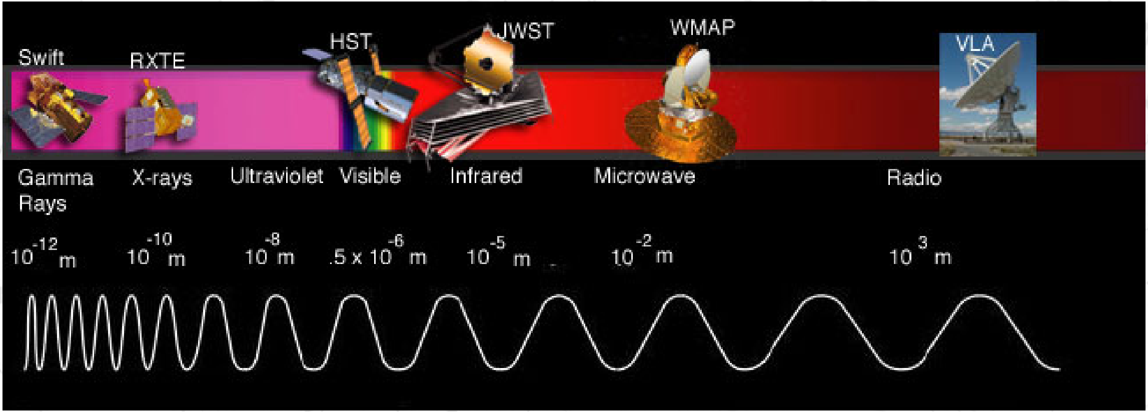
James Webb Space Telescope (JWST)



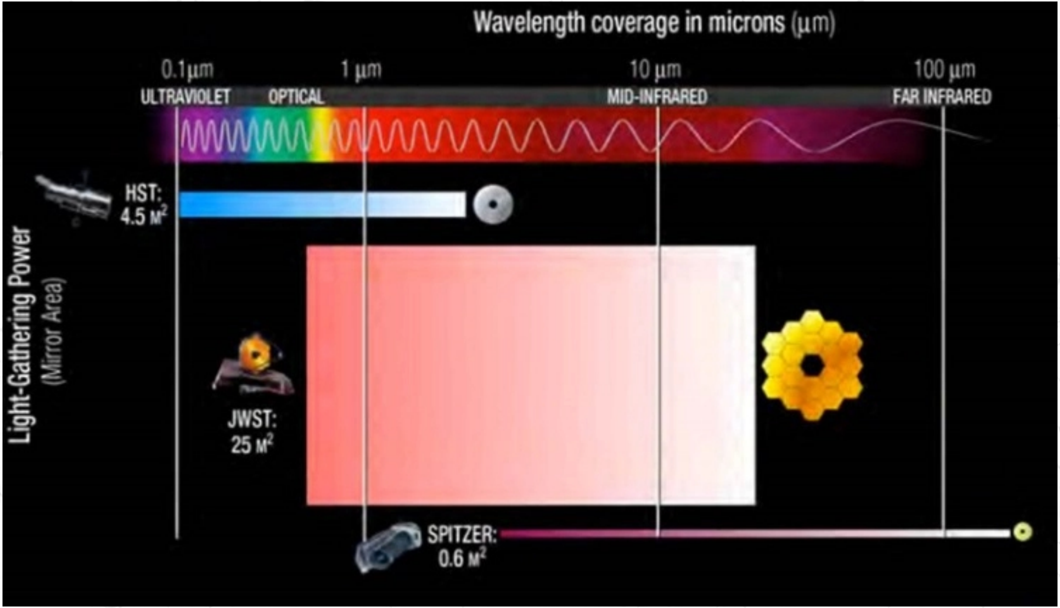
James Webb Space Telescope (JWST)

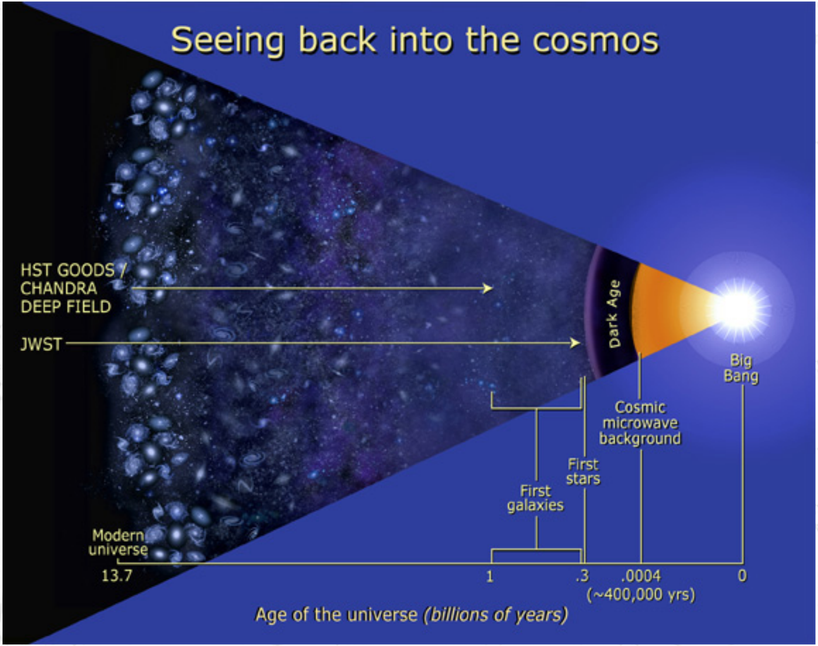


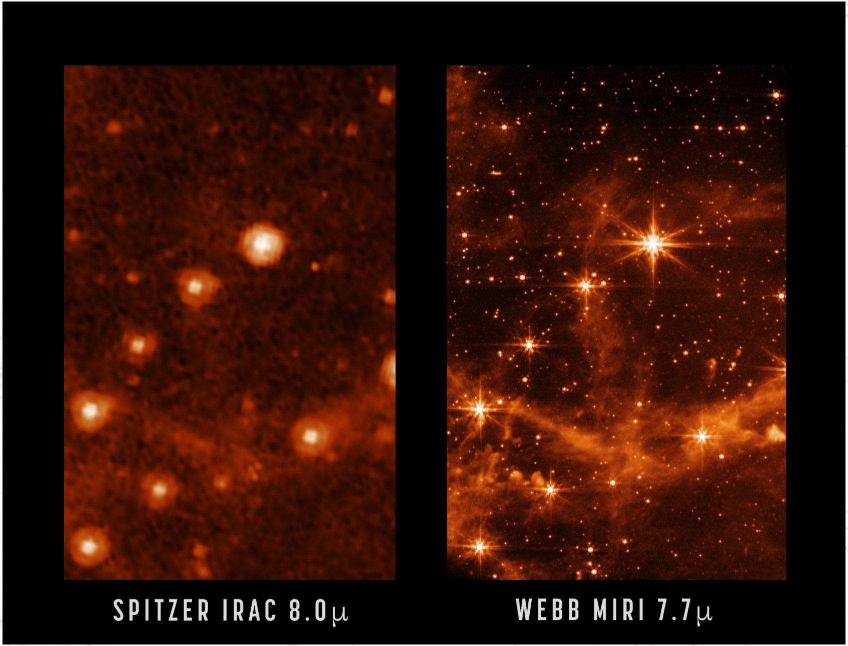
Hubble Probes the Early Universe
1990
Ground-based observatories
1995
Hubble Deep Field
2004
Hubble Ultra Deep Field
2010
Hubble Ultra Deep Field-IR
FUTURE
James Webb Space Telescope
Redshift (z):
1
4
5
6
7
8
10
>20
Time after the Big Bang
Present
6 billion years
1.5 billion years
800 million years
480 million years
200 million years

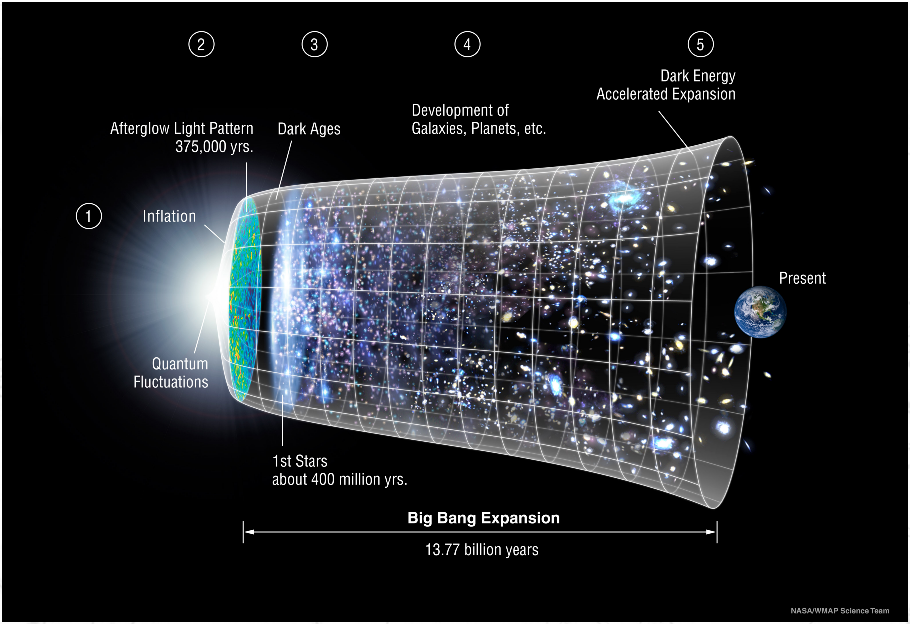


Swift
RXTE
HST
JWST
WMAP
VLA
Gamma Rays
X-rays
Ultraviolet
Visible
Infrared
Microwave
Radio
10^{-12} m
10^{-10} m
10^{-8} m
$.5 \times 10^{-6}$ m
10^{-5} m
10^{-2} m
10^{3} m


Wavelength coverage in microns (μm)
0.1μm
1 μm
10 μm
100 μm
ULTRAVIOLET
OPTICAL
MID-INFRARED
FAR INFRARED
HST:
4.5 M²
Light-Gathering Power
(Mirror Area)
JWST:
25 M²
SPITZER:
0.6 M²


Seeing back into the cosmos
HST GOODS / CHANDRA DEEP FIELD
JWST
Dark Age
Big Bang
Cosmic microwave background
First stars
First galaxies
Modern universe
13.7
1
.3
.0004
(~400,000 yrs)
0
Age of the universe (billions of years)


SPITZER IRAC 8.0μ
WEBB MIRI 7.7μ



The ΛCDM (Lambda cold dark matter) or Lambda-CDM model

The ΛCDM (Lambda cold dark matter) or Lambda-CDM model

For further references, see NASA / LAMBDA Archive
or go to the next url:
https://lambda.gsfc.nasa.gov/education/graphic_history/univ_evol.html

There was an earlier alert

- In 2016, Hubble discovered some extremely far-off galaxies. The most distant of these was GN-z11, a dim smudge that was discovered and dated to 400 million years after the Big Bang.

  A Remarkably Luminous Galaxy at z=11.1 Measured with Hubble Space Telescope Grism Spectroscopy,
  P. A. Oesch et. al,
  arXiv: 1603.00461

- Even though it was unusually early for a galaxy, the fact that it stood alone and was so small (about 1% the mass of the Milky Way) meant that it did not cast doubt on the ΛCDM hypothesis.
- To discover if GN-z11 was an anomaly or a member of a wider population of puzzlingly early galaxies, which could help determine whether we are missing a key component of the "ΛCDM recipe", astronomers needed a more powerful telescope.

Discovering a fossilized rabbit in Precambrian rock

- Last spring, as the James Webb Space Telescope (JWST) opened its lens, extremely far-off but brilliant galaxies shone into the telescope's field of view.
- The earliest of those confirmed galaxies, which currently holds the record for the universe's earliest structure, first released light 330 million years after the Big Bang.
- Astronomers confirmed in December that some of the galaxies are actually as far away and, consequently, as distance, as they appear.
- Astronomers started to wonder if the abundance of early massive things contradicted our existing knowledge of the cosmos.
- The observations from the telescope were defying the accepted theory of cosmology, a tried-and-true system of equations known as the lambda cold dark matter model, or ΛCDM model, and thrillingly pointing to new cosmic constituents or governing laws.
- Astronomers are reconsidering how galaxies are created, particularly in the cosmic beginning, because the ΛCDM hypothesis is robust. That doesn't necessarily mean the instance of the too-early galaxies won't end up being noteworthy.

Discovering a fossilized rabbit in Precambrian rock

- Astronomers who worked on the first study using JWST data noticed a galaxy that seemed unusually bright and far away. Its designation, GLASS-z13, denotes that it is farther distant than anything previously observed, with an apparent distance at a redshift of 13. Later, the galaxy's redshift was reduced to 12.4, and its designation was changed to GLASS-z12.

  Two Remarkably Luminous Galaxy Candidates at $z \approx 10 - 12$ Revealed by JWST, Rohan P. Naidu et. al, arXiv: 2207.09434

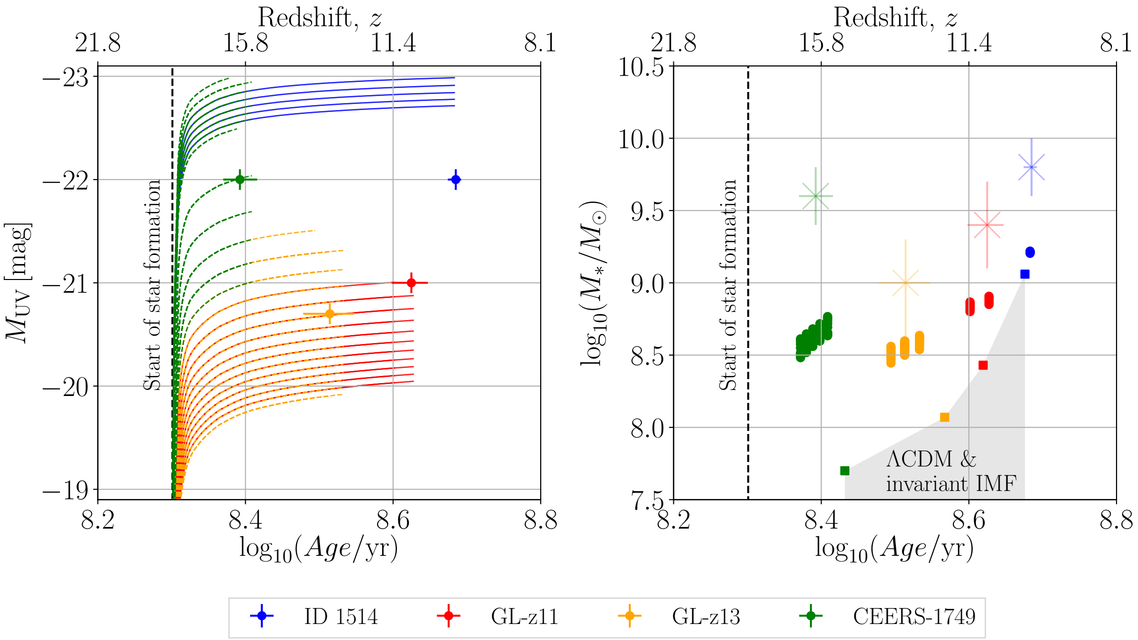
- A galaxy known as CEERS-1749 or CR2-z17-1, whose light appears to have left it 13.7 billion years ago, just 220 million years after the Big Bang - barely an eyeblink after the beginning of cosmic time, was reported by other astronomers working on the various sets of JWST observations to have a redshift value of 11 to 20.

  Schrodinger's Galaxy Candidate: Puzzlingly Luminous at $z \approx 17$, or Dusty/Quenched at $z \approx 5$?, Rohan P. Naidu et. al, arXiv: 2208.02794

Visible matter interacts and behaves in complex ways

- These alleged discoveries suggested that the clean narrative known as the ΛCDM might not be complete. Galaxies instantly grew massive for some reason. Massive galaxies aren't something you anticipate finding in the early cosmos. They haven't had enough time to develop as many stars, and they haven't combined.
- The early, brilliant galaxies observed by JWST were found to be an order of magnitude heavier than the galaxies that formed concurrently in the computer simulations of universes guided by the ΛCDM model.

  Has JWST already falsified dark-matter-driven galaxy formation?, Moritz Haslbauer et. al, arXiv: 2210.14915
- Not all cosmologists agreed with the allegation made by certain astronomers that JWST was shattering cosmology. The forecasts made by CDM have the drawback of not always being precise. Dark matter and dark energy are basic, but visible matter exhibits complicated interactions and behaviors, and the details of the first few years following the Great Bang remain unknown.

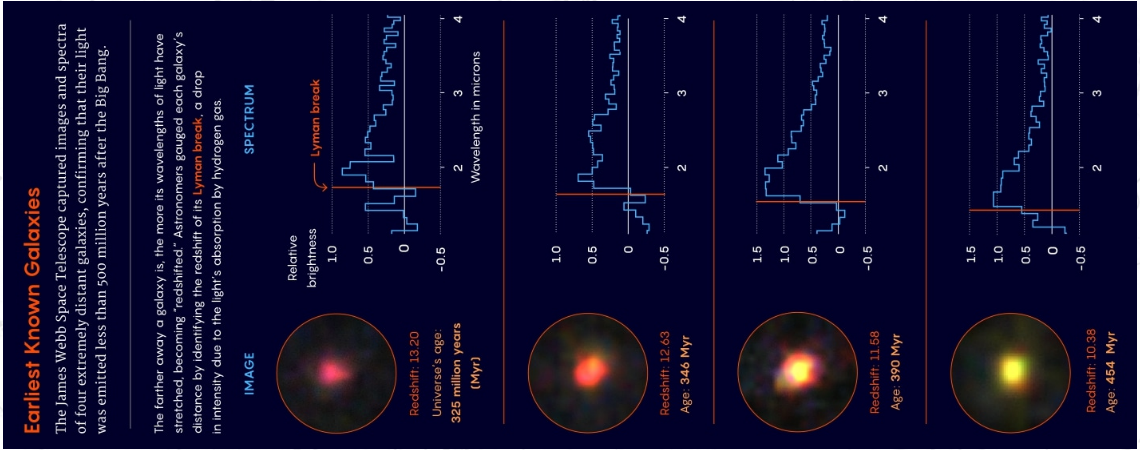


Redshift, z
21.8
15.8
11.4
8.1
M_{UV} [mag]
−23
−22
−21
−20
−19
Start of star formation
8.2
8.4
8.6
8.8
$\log_{10}(Age/\mathrm{yr})$
Redshift, z
21.8
15.8
11.4
8.1
$\log_{10}(M_*/M_\odot)$
10.5
10.0
9.5
9.0
8.5
8.0
7.5
Start of star formation
ΛCDM &
invariant IMF
8.2
8.4
8.6
8.8
$\log_{10}(Age/\mathrm{yr})$
ID 1514
GL-z11
GL-z13
CEERS-1749

The Lyman Break

- The JWST Advanced Deep Extragalactic Survey (JADES) team looked for galaxies whose Lyman break, or abrupt cutoff, of infrared light occurs at a specific wavelength. This breach happens as a result of light absorption by hydrogen that is floating between galaxies. The wavelength of that abrupt break shifts as a result of the universe's ongoing expansion, which also causes the light from far-off galaxies to change its wavelength. A galaxy is farther away if its light seems to diminish at longer wavelengths. Redshifts up to 13.2 were found by JADES, indicating that the galaxy's light was produced 13.4 billion years ago.

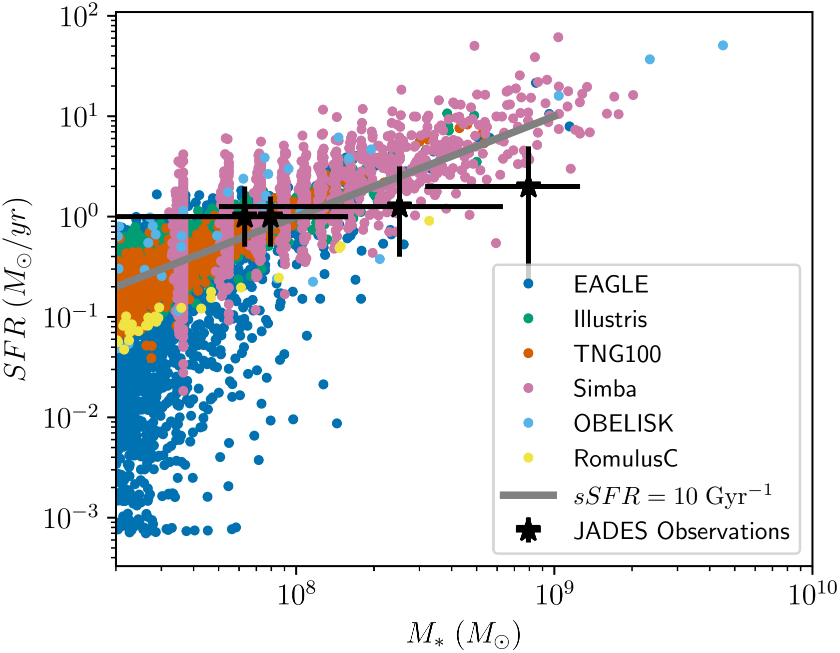
  Discovery and properties of the earliest galaxies with confirmed distances,
  B. E. Robertson et. al,
  arXiv: 2212.04480



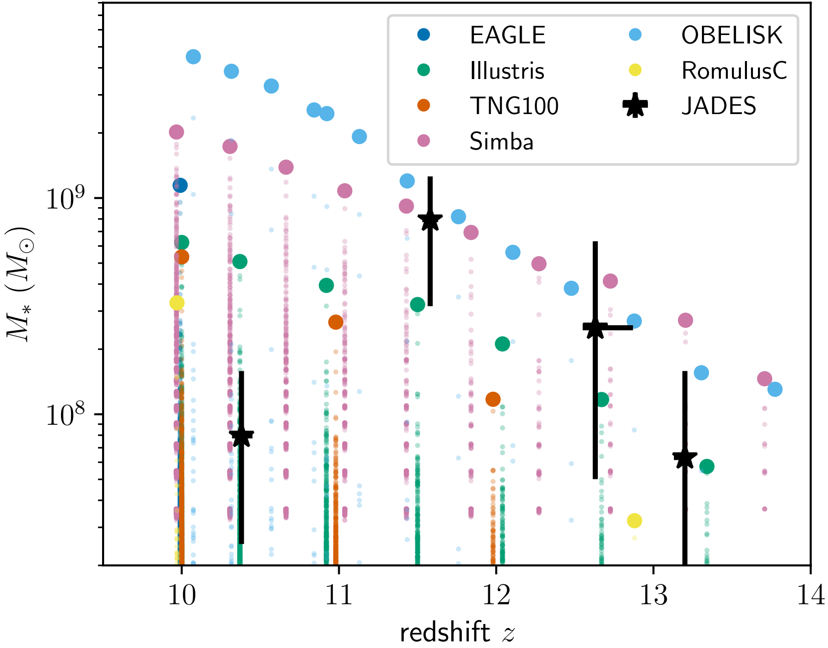
The Lyman Break

- Throughout the first billion years of the universe's existence, galaxies evolved 10 times more quickly than they do now.
- One fundamental presumption is the initial mass function (IMF), which states that stars always form within a specific statistical range of masses. The IMF, however, might have been different in the early universe. The ΛCDM model's basic input can be changed to produce practically any desired result.
- A significant supercomputer simulation of ΛCDM universes revealed that the simulations could create galaxies as massive as the four that the JADES team spectroscopically examined. These four stand out because they are both smaller and fainter than other alleged early galaxies like GLASS-z12.

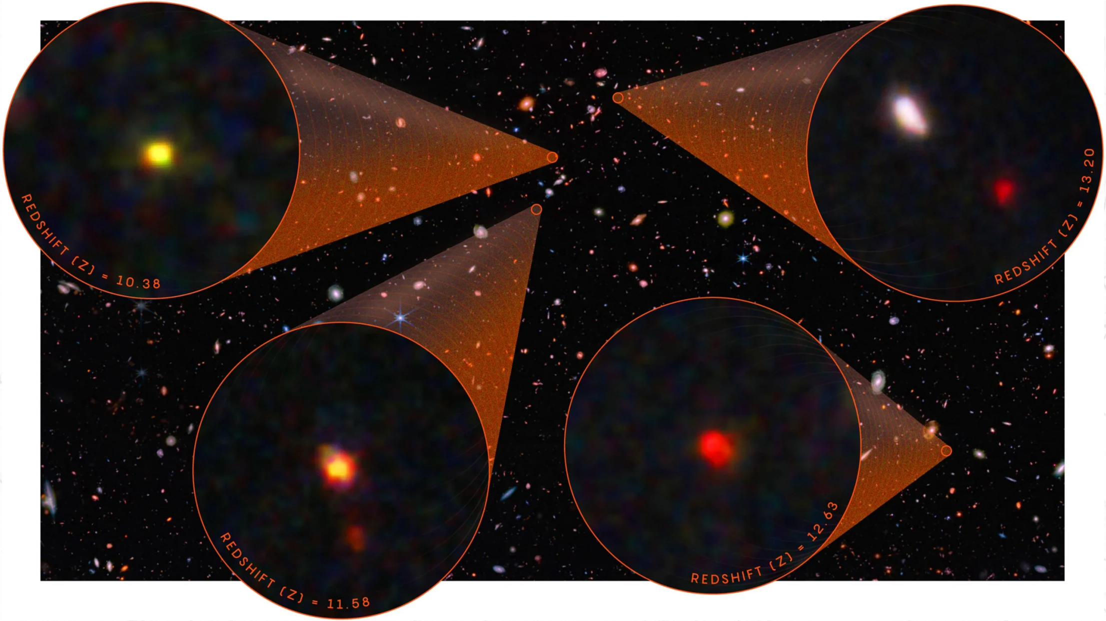
Can Cosmological Simulations Reproduce the Spectroscopically Confirmed Galaxies Seen at $z \geq 10$?,
B.W. Keller, F. Munshi, M. Trebitsch and M. Tremmel,
arXiv: 2212.12804



$SFR\ (M_\odot/yr)$
$M_*\ (M_\odot)$
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{8}
10^{9}
10^{10}
EAGLE
Illustris
TNG100
Simba
OBELISK
RomulusC
$sSFR = 10\ \mathrm{Gyr}^{-1}$
JADES Observations



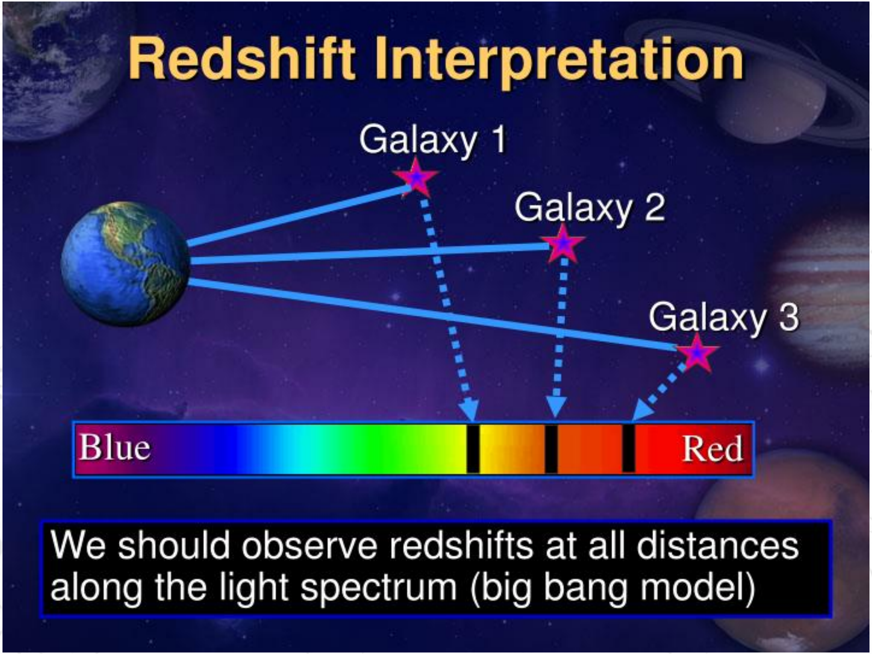
EAGLE
Illustris
TNG100
Simba
OBELISK
RomulusC
JADES
$M_* \ (M_\odot)$
10^9
10^8
10
11
12
13
14
redshift z

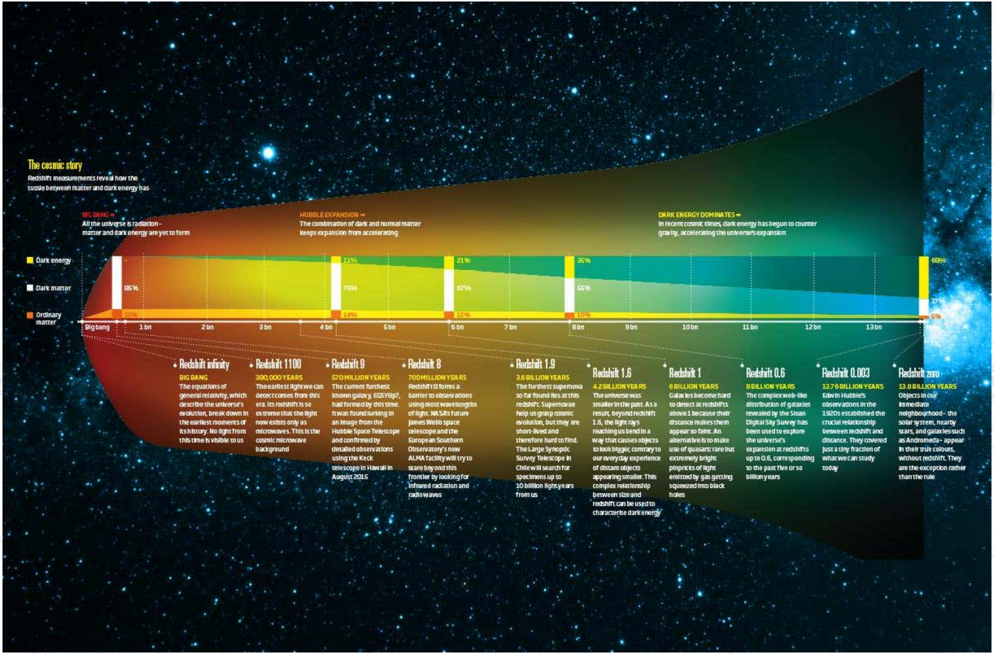


CEERS-1749, GL-z13, GL-z11, and ID 1514

Red Shift (Z) Values for the Spacetime Map

18 Billion Year Universe Hubble Constant = 54.3 km/sec/Mpc		17 Billion Year Universe Hubble Constant = 57.5 km/sec/Mpc		16 Billion Year Universe Hubble Constant = 61.1 km/sec/Mpc		15 Billion Year Universe Hubble Constant = 65.2 km/sec/Mpc		14 Billion Year Universe Hubble Constant = 69.8 km/sec/Mpc	
Byr	Z	Byr	Z	Byr	Z; recessional velocity (1,000 km/sec)	Byr	Z	Byr	Z
18	0	17	0	16	0; 0	15	0	14	0
17	0.06	16	0.06	15	0.07; 19	14	0.07	13	0.08
16	0.13	15	0.13	14	0.14; 39	13	0.15	12	0.17
15	0.2	14	0.21	13	0.23; 61	12	0.25	11	0.27
14	0.29	13	0.31	12	0.33; 83	11	0.36	10	0.40
13	0.38	12	0.42	11	0.45; 107	10	0.50	9	0.56
12	0.5	11	0.55	10	0.6; 131	9	0.67	8	0.75
11	0.64	10	0.7	9	0.78; 156	8	0.88	7	1.0
10	0.8	9	0.89	8	1.0; 180	7	1.14	6	1.33
9	1.0	8	1.13	7	1.29; 204	6	1.50	5	1.8
8	1.25	7	1.43	6	1.67; 226	5	2.0	4	2.50
7	1.6	6	1.8	5	2.2; 247	4	2.75	3	3.67
6	2.0	5	2.4	4	3.0; 265	3	4.0	2	6.0
5	2.6	4	3.25	3	4.3; 279	2	6.5	1	13
4	3.5	3	4.7	2	7.0; 291	1	14	0	infinity
3	5.0	2	7.5	1	15.0; 298	0	infinity	.	.
2	8.0	1	16.0	0	infinity; c	.	.	.	.
1	17.0	0	infinity	.	.	.	.	.	.
0	infinity	.	.	.	.	.	.	.	.
John A. Gowan 6 May 2001 Reproduction Permitted with Attribution http://www.people.cornell.edu/pages/jag8									


Redshift Interpretation
Galaxy 1
Galaxy 2
Galaxy 3
Blue
Red
We should observe redshifts at all distances along the light spectrum (big bang model)



The cosmic story
Redshift measurements reveal how the tussle between matter and dark energy has
BIG BANG
All the universe is radiation – matter and dark energy are yet to form
HUBBLE EXPANSION
The combination of dark and normal matter keeps expansion from accelerating
DARK ENERGY DOMINATES
In recent cosmic times, dark energy has begun to counter gravity, accelerating the universe's expansion
Dark energy
Dark matter
Ordinary matter
85%
15%
11%
75%
14%
21%
67%
12%
35%
55%
10%
68%
27%
5%
Big bang
1 bn
2 bn
3 bn
4 bn
5 bn
6 bn
7 bn
8 bn
9 bn
10 bn
11 bn
12 bn
13 bn
Redshift infinity
BIG BANG
The equations of general relativity, which describe the universe's evolution, break down in the earliest moments of its history. No light from this time is visible to us
Redshift 1100
380,000 YEARS
The earliest light we can detect comes from this era. Its redshift is so extreme that the light now exists only as microwaves. This is the cosmic microwave background
Redshift 9
570 MILLION YEARS
The current furthest known galaxy, EGSY8p7, had formed by this time. It was found lurking in an image from the Hubble Space Telescope and confirmed by detailed observations using the Keck telescope in Hawaii in August 2015
Redshift 8
700 MILLION YEARS
Redshift 8 forms a barrier to observations using most wavelengths of light. NASA's future James Webb space telescope and the European Southern Observatory's new ALMA facility will try to stare beyond this frontier by looking for infrared radiation and radiowaves
Redshift 1.9
3.6 BILLION YEARS
The furthest supernova so far found lies at this redshift. Supernovae help us grasp cosmic evolution, but they are short-lived and therefore hard to find. The Large Synoptic Survey Telescope in Chile will search for specimens up to 10 billion light years from us
Redshift 1.6
4.2 BILLION YEARS
The universe was smaller in the past. As a result, beyond redshift 1.6, the light rays reaching us bend in a way that causes objects to look bigger, contrary to our everyday experience of distant objects appearing smaller. This complex relationship between size and redshift can be used to characterise dark energy
Redshift 1
6 BILLION YEARS
Galaxies become hard to detect at redshifts above 1 because their distance makes them appear so faint. An alternative is to make use of quasars: rare but extremely bright pinpricks of light emitted by gas getting squeezed into black holes
Redshift 0.6
8 BILLION YEARS
The complex web-like distribution of galaxies revealed by the Sloan Digital Sky Survey has been used to explore the universe's expansion at redshifts up to 0.6, corresponding to the past five or so billion years
Redshift 0.003
13.76 BILLION YEARS
Edwin Hubble's observations in the 1920s established the crucial relationship between redshift and distance. They covered just a tiny fraction of what we can study today
Redshift zero
13.8 BILLION YEARS
Objects in our immediate neighbourhood – the solar system, nearby stars, and galaxies such as Andromeda – appear in their true colours, without redshift. They are the exception rather than the rule